Commissioning of the ATLAS Liquid Argon Calorimeter

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on behalf of the ATLAS Liquid Argon Calorimeter Group

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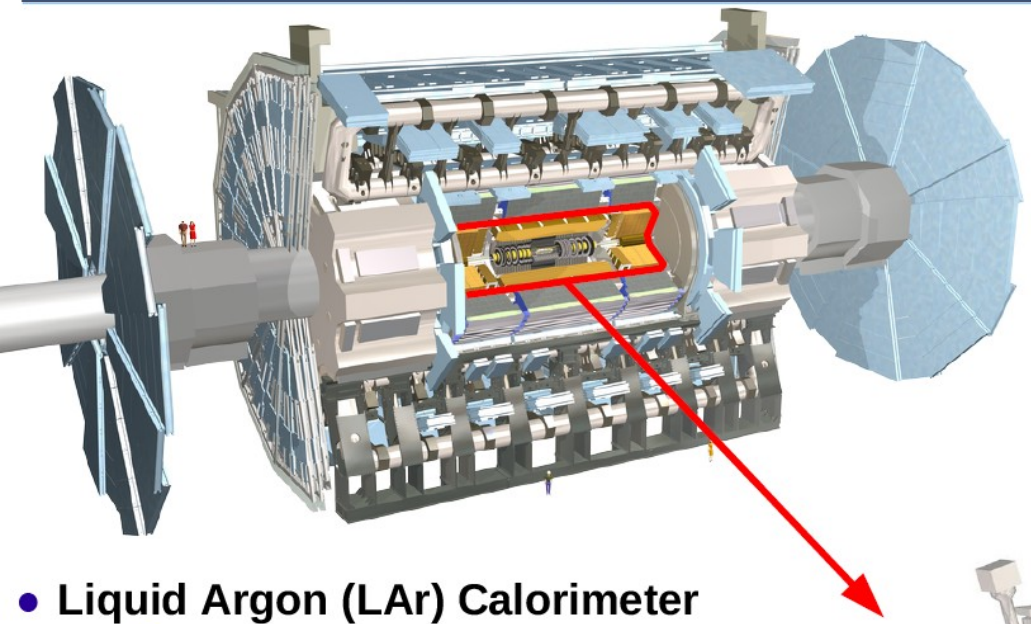
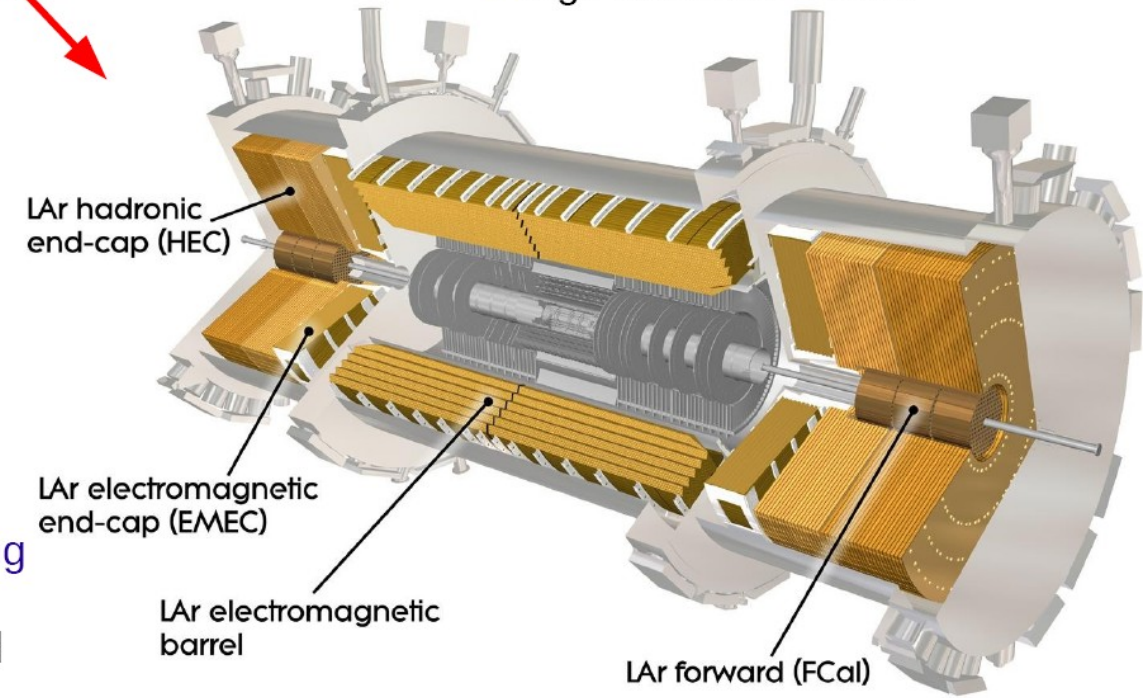
October 5, 2009

The Liquid Argon (LAr) Calorimeter of the ATLAS Experiment



- **The ATLAS experiment**
  - general purpose detector at the LHC, at CERN
- **LHC environment**
  - proton-proton collisions ($\sqrt{s}$ = 14 TeV) every 25 ns
  - ~900 M inelastic collisions per second at design luminosity
    - high interaction rate
    - high radiation doses

- **Liquid Argon (LAr) Calorimeter**
  - sampling calorimeter
  - intrinsically radiation-hard
  - Very good electromagnetic calorimetry
    - main benchmarks : $H \rightarrow \gamma\gamma, Z' \rightarrow ee$
    - identification and measurement over a large dynamic (50 MeV → TeV : 16 bits)
  - Hermetic jet and transverse missing energy calorimetry
    - Hadronic End-Cap and Forward Calorimeter

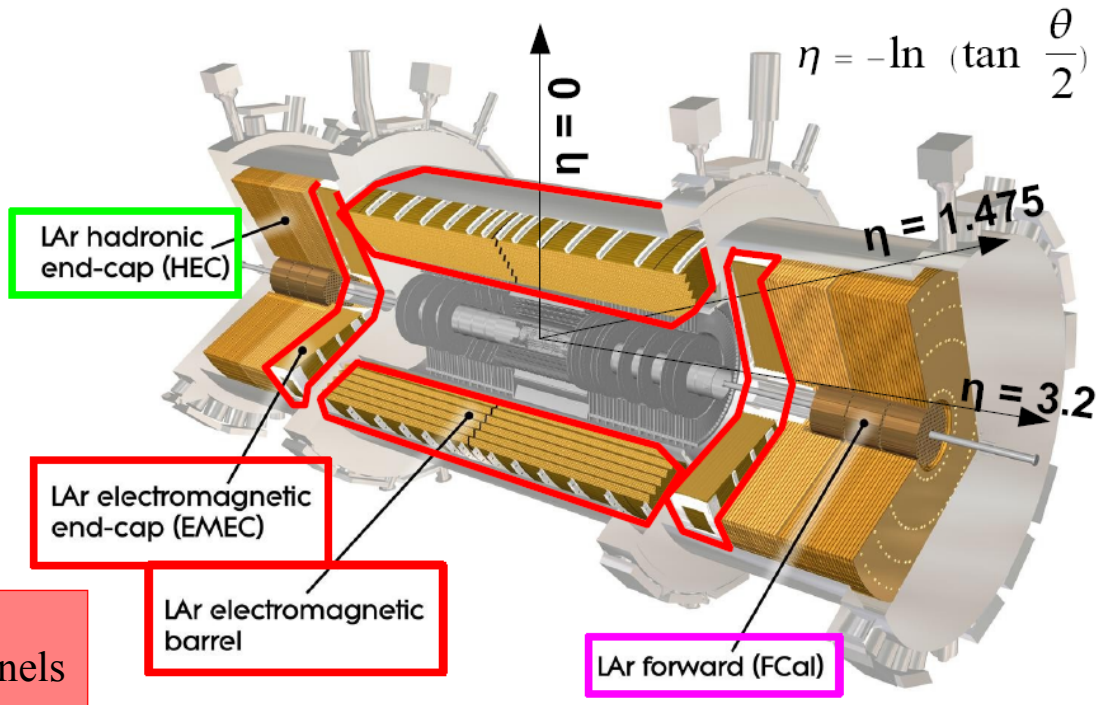


The Electromagnetic Calorimeter

- **Hadronic End-Cap [Cu + LAr]**
  - Flat-plat design
    - ➲ Coverage : 1.5 < |η| < 3.2
  - Resolution :

$$\frac{\Delta E}{E} = \frac{50\%}{\sqrt{E(GeV)}} \oplus 3\%$$

  - 4 sampling depths
    - ➲ ~ 11 λ in total 5,632 channels



- **Electromagnetic Calorimeter [Pb + LAr]** 173,312 channels
  - Accordion geometry providing an uniform φ coverage without crack
    - ➲ Barrel + End-cap : |η| < 3.2
  - Resolution :

$$\frac{\Delta E}{E} = \frac{10\%}{\sqrt{E(GeV)}} \oplus 0.7\%$$

  - 3 sampling depths (|η| < 2.5)
    - ➲ ~ 22-30 X_0 in total
    - ➲ + one presampler (|η| < 1.8)

- **Forward Calorimeter [Cu/W + LAr]**
  - Small LAr gaps between rods and tubes parallel to the beam axis
    - ➲ Coverage : 3.1 < |η| < 4.9
  - Resolution :

$$\frac{\Delta E}{E} = \frac{100\%}{\sqrt{E(GeV)}} \oplus 10\%$$

  - 3 sampling depths 3,524 channels
    - ➲ 1 EM (Cu) / 2 HAD (W)
    - ➲ ~ 11 λ in total

The Hadronic End-Cap Calorimeter

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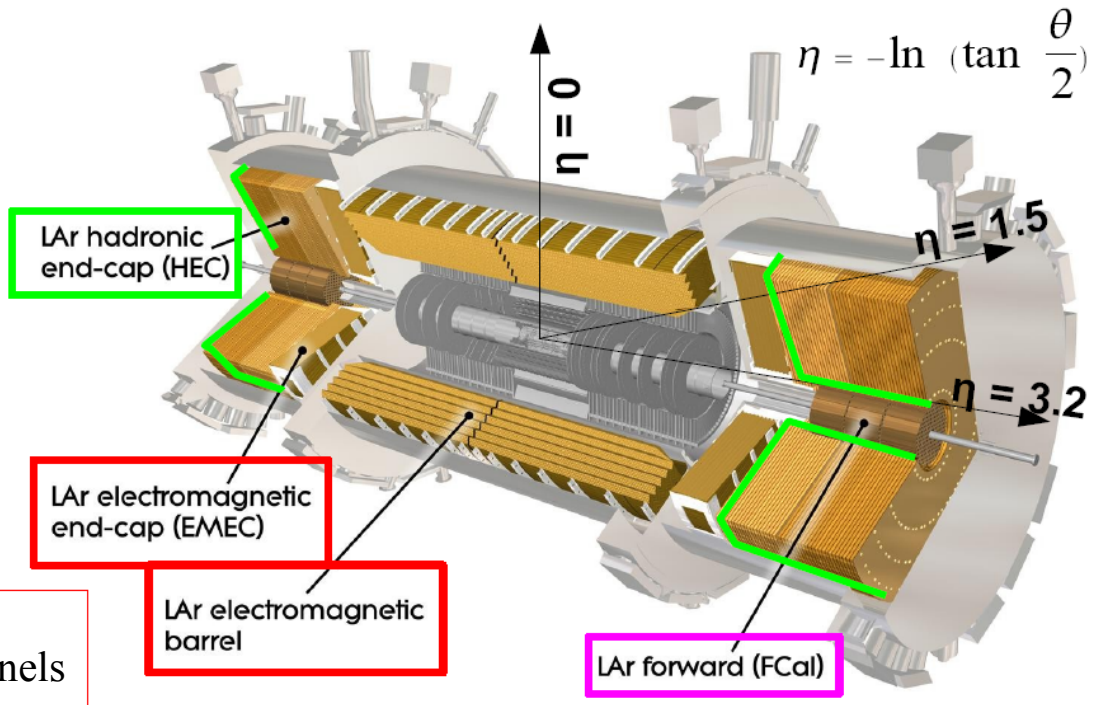

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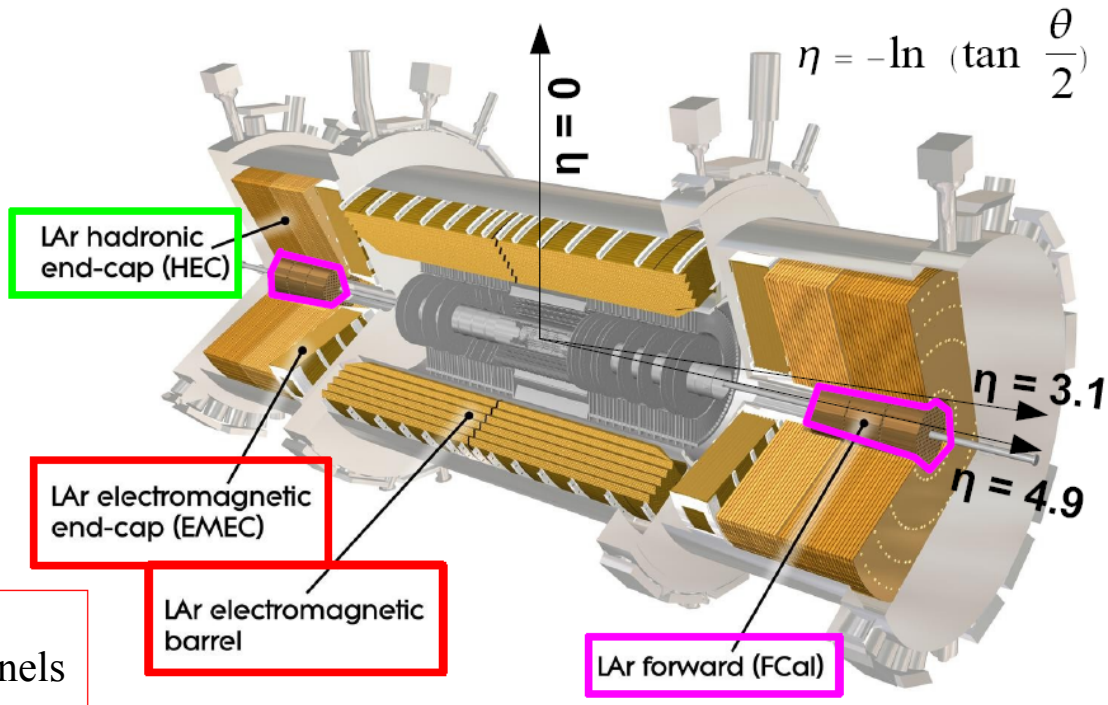

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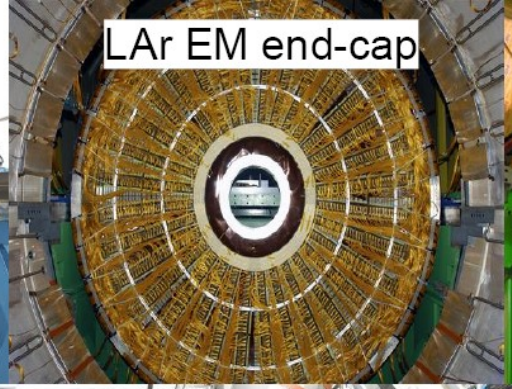
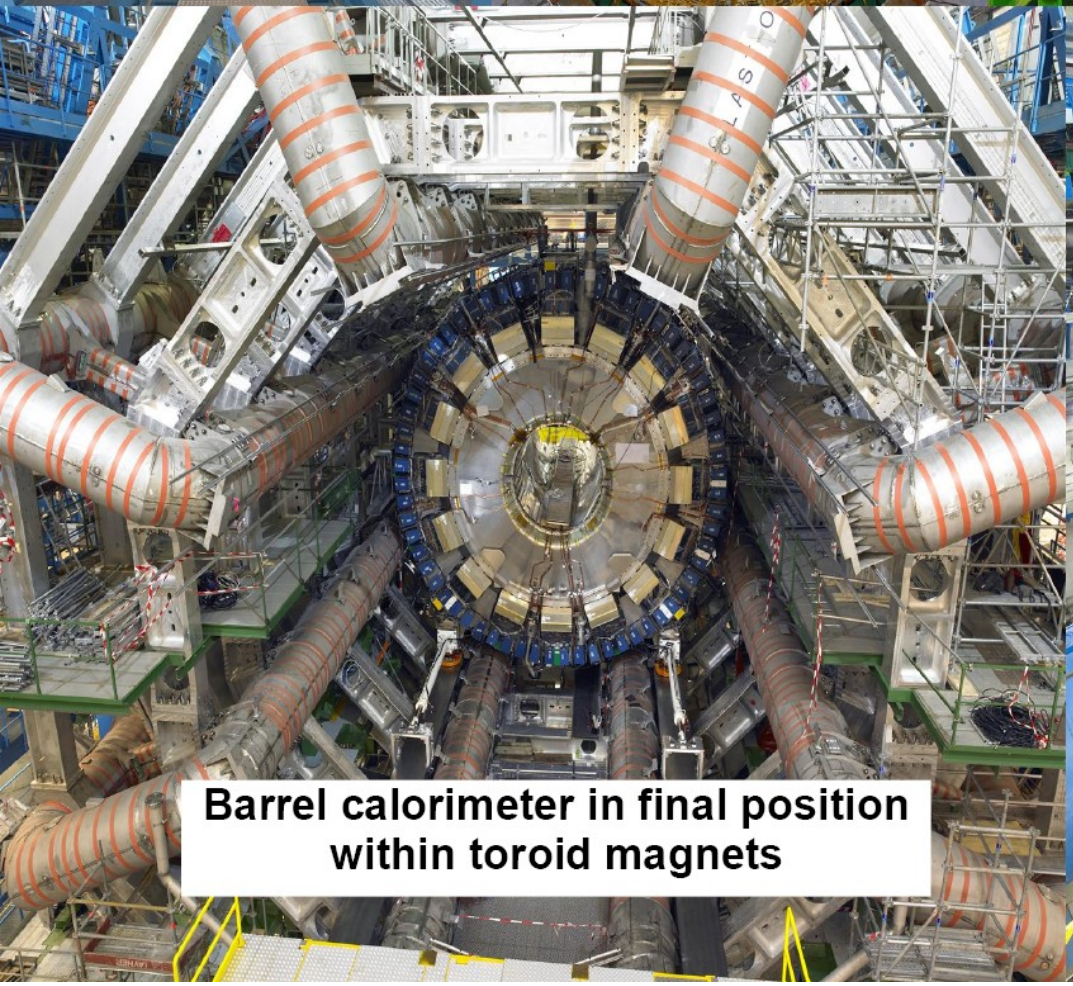
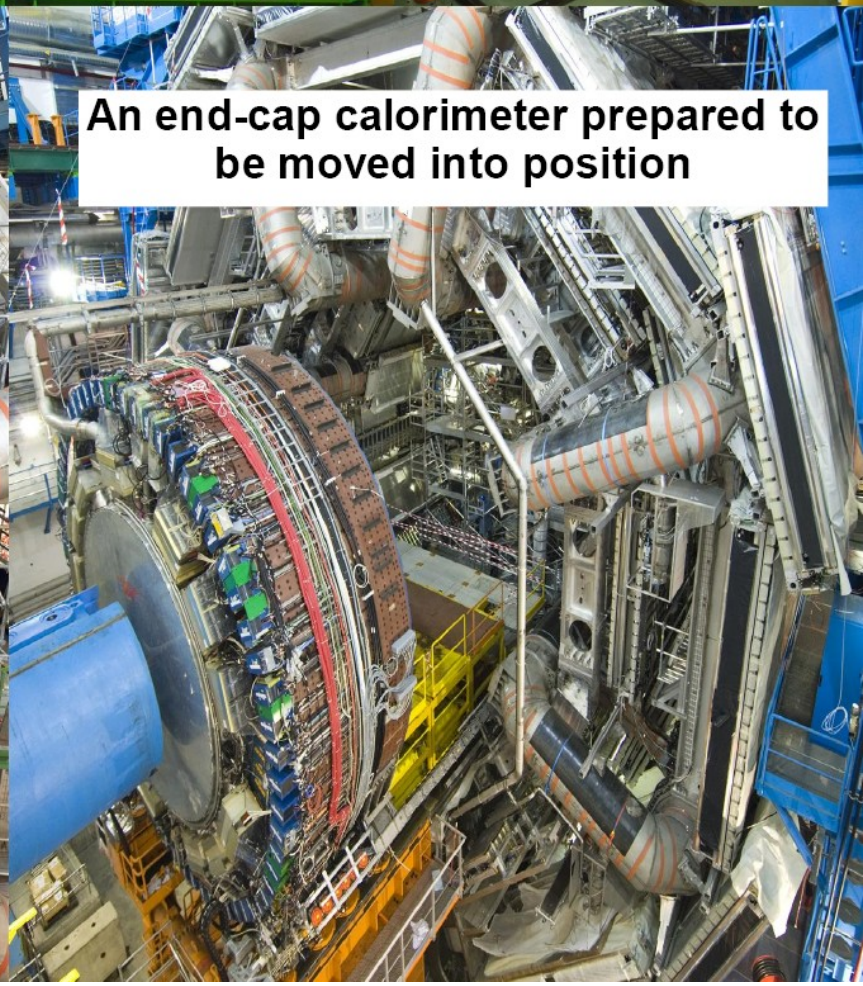
LAr EM barrel


LAr EM end-cap


LAr HAD end-cap


LAr forward

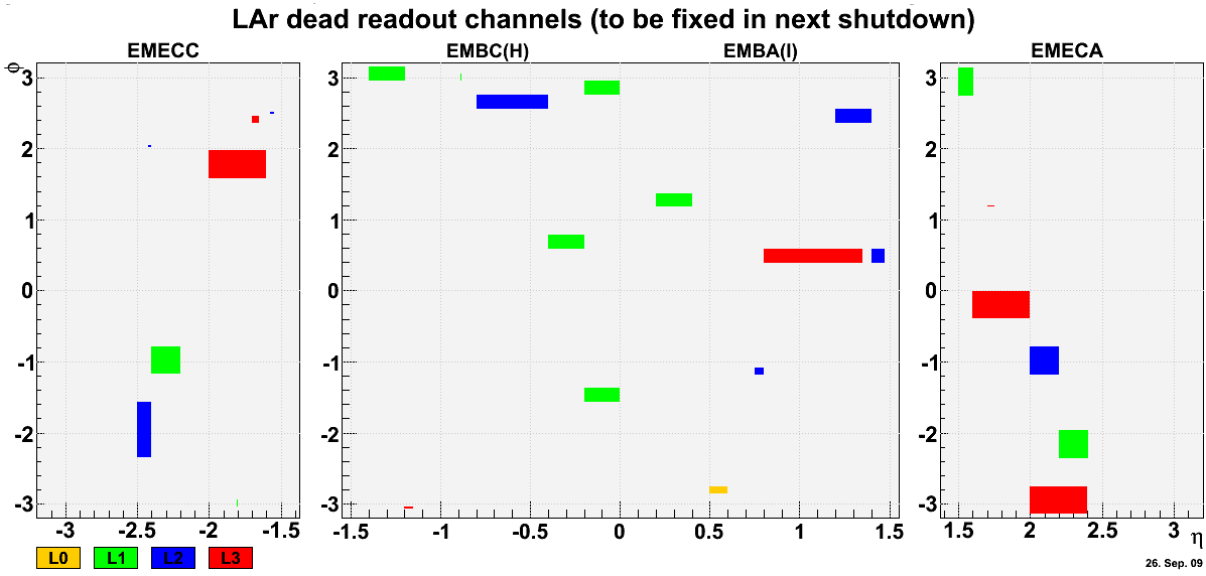

Barrel calorimeter in final position
within toroid magnets

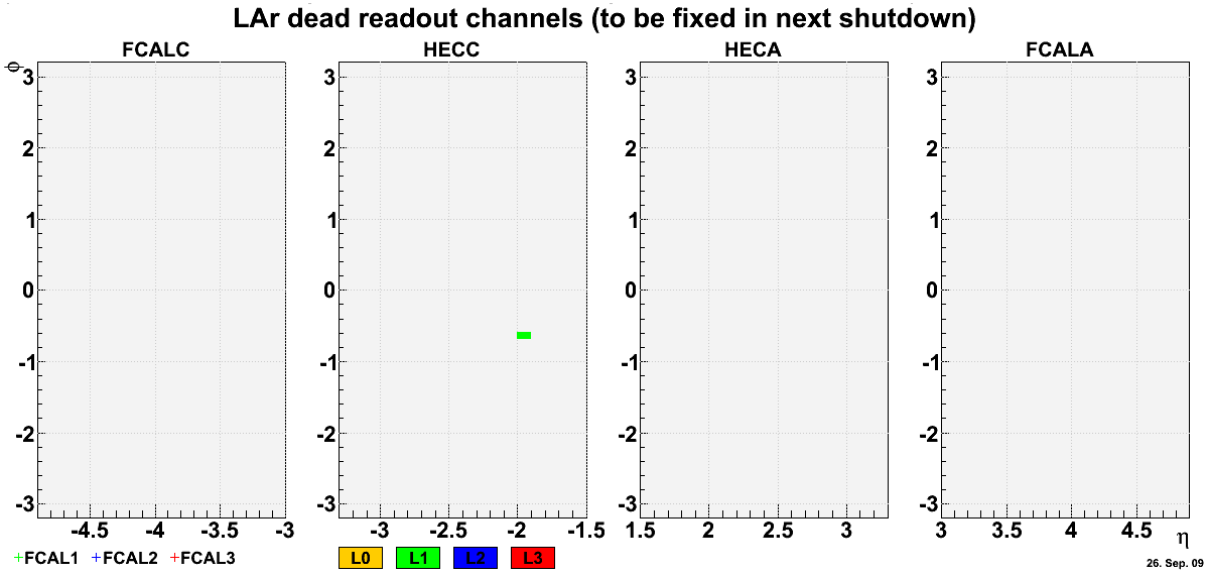

An end-cap calorimeter prepared to
be moved into position

Detector Status

(from September 26, 2009)

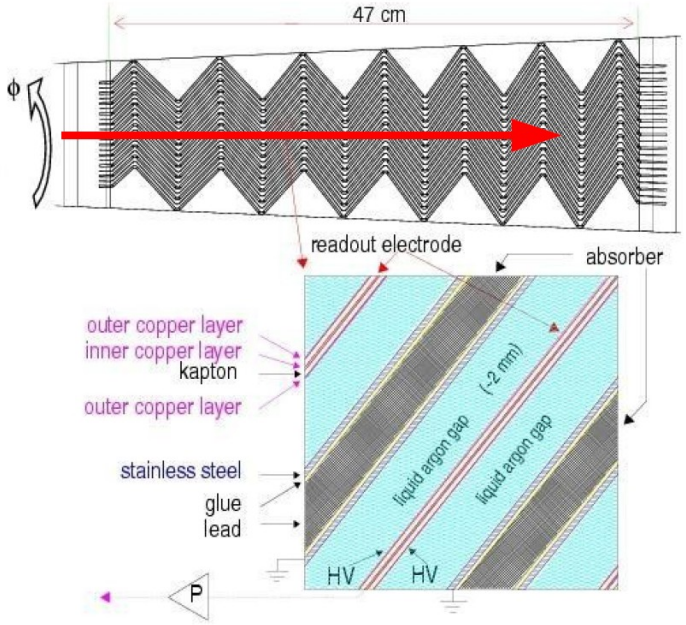
- ~182k total channels
- Only 36 (<0.02%) permanently dead
  - E.g. problem inside cryostat
- ~1.2% with dead readout
  - Mostly bad optical transmitters on front end boards
  - To be fixed at next access
- <0.4% with broken calibration lines (calibration degraded by ~2%)
- <0.1% with large noise
- Channels exercised with regular calibration and cosmic runs.

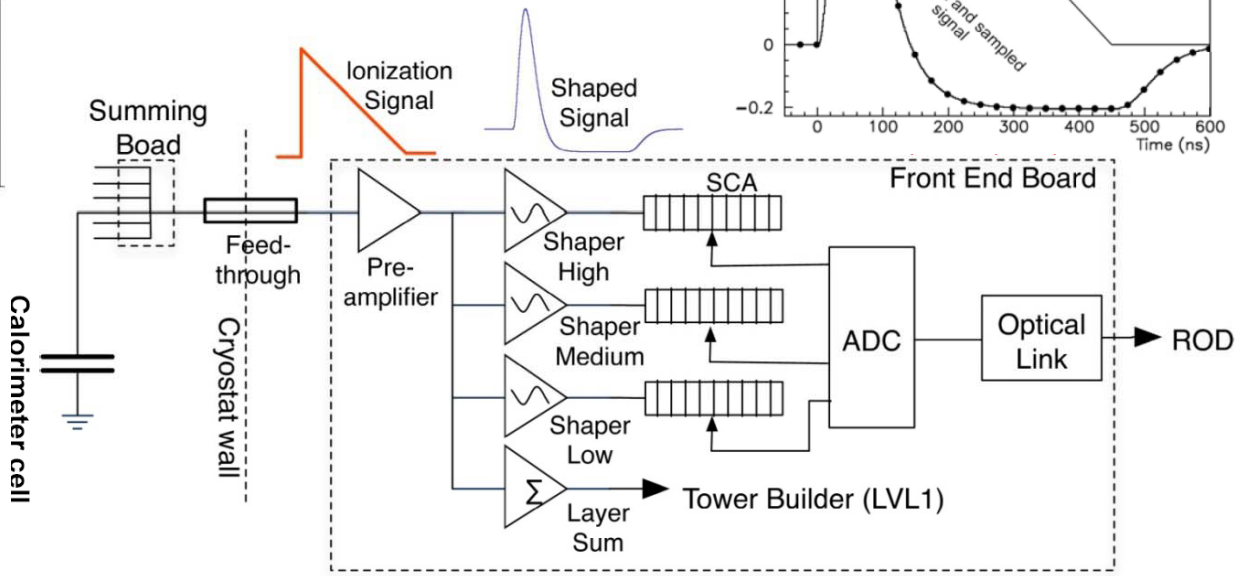


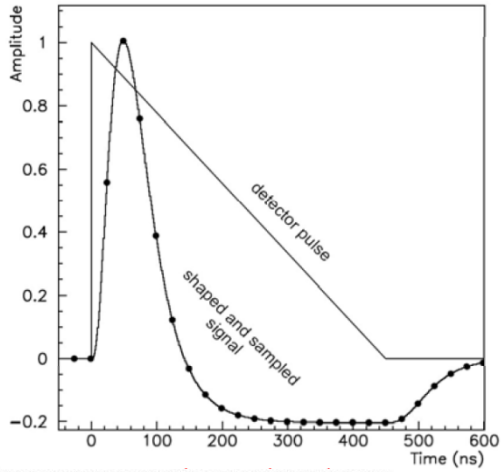


Ionization and Signal Processing

- Shower develops in absorber
- LAr ionization electrons collected with ~1 kV/mm HV







- Front End Boards, on detector, receive ionization signals and
  - Amplify them, give them a bipolar shape (3 gains, ~1:10:100)
  - Sample and store them (~2.5 μs) while awaiting a L1 trigger decision
  - Select the gain, digitize, and transmit the signal upon L1 accept
  - Energy is calculated in back-end, off-detector, electronics

Energy Reconstruction and Calibration

$$E_{\text{cell}} = F_{\mu A \to \text{MeV}} \cdot F_{DAC \to \mu A} \cdot \frac{1}{\frac{M_{\text{phys}}}{M_{\text{cali}}}} \cdot R \left[\sum_{j=1}^{N_{\text{samples}}} a_j \left(s_j - p \right) \right]$$

ADC to DAC (Ramps)

Pulse Samples

Cell energy

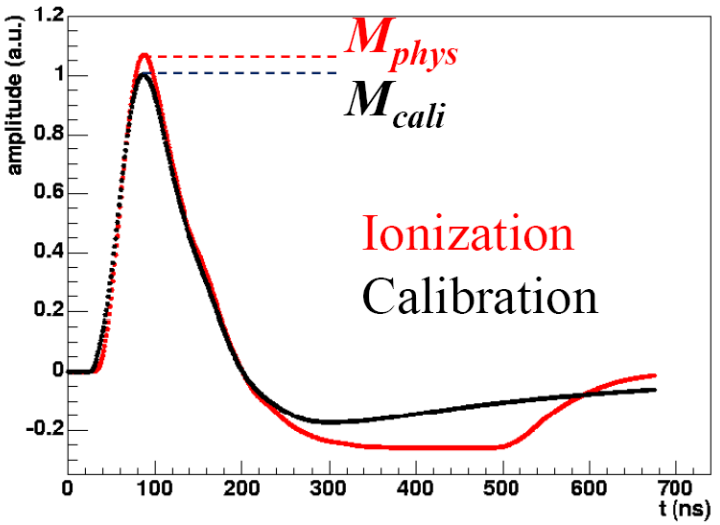
Sampling fraction

Calibration board

Optimal Filtering Coefficients

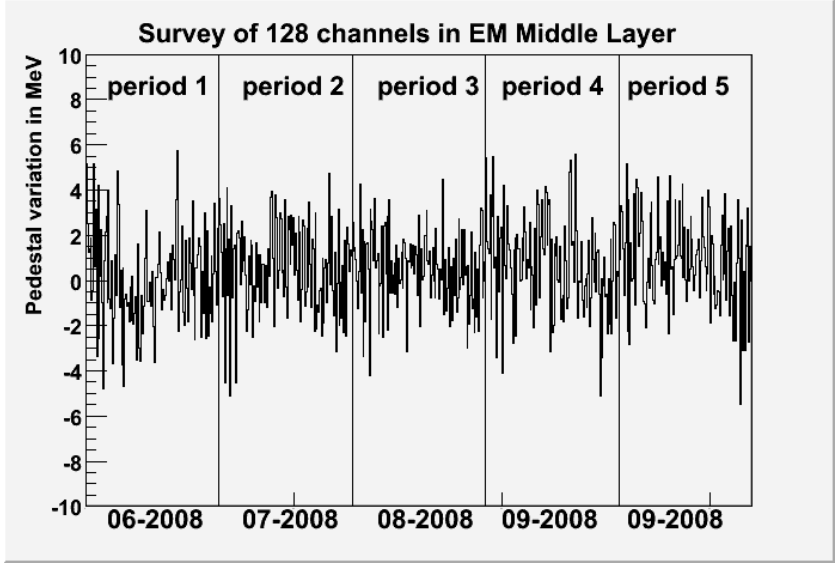
Pedestals

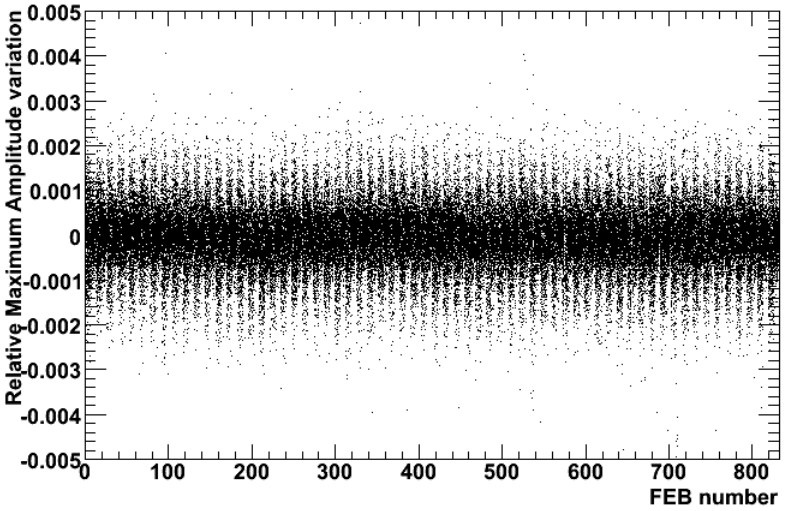
- Electronic calibration runs taken regularly
  - Calibration board delivers precise current to injection resistors at cell input (for EM calorimeters)
  - Pedestal runs, ramp runs to measure gain (ADC to DAC), delay runs to measure pulse shape
  - Exponential calibration input vs. triangular input from ionization
- Optimal Filtering Coefficients from ionization pulse prediction, using delay runs as input
- Sampling fraction from test beam and simulation
- DAC → μA property of calibration board
- Cell energies computed in back-end electronics or offline



Stability of Calibration Constants

- Calibration runs planned between every LHC fill
- If significant changes are seen, calibration database is updated
- Pedestals are stable at the few MeV level over a period of months, here for one Front End Board (128 channels)
- Electronic noise for this layer ~25 MeV

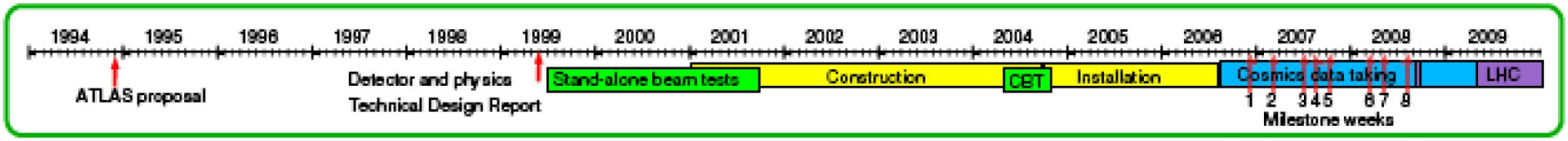




- Amplitude of calibration pulses in delay runs stable at the 0.1% level
- Here comparing two calibration runs for whole LAr Barrel (~100k channels)
- Sensitive to stability of calibration pulse, shaper, pedestals, etc.

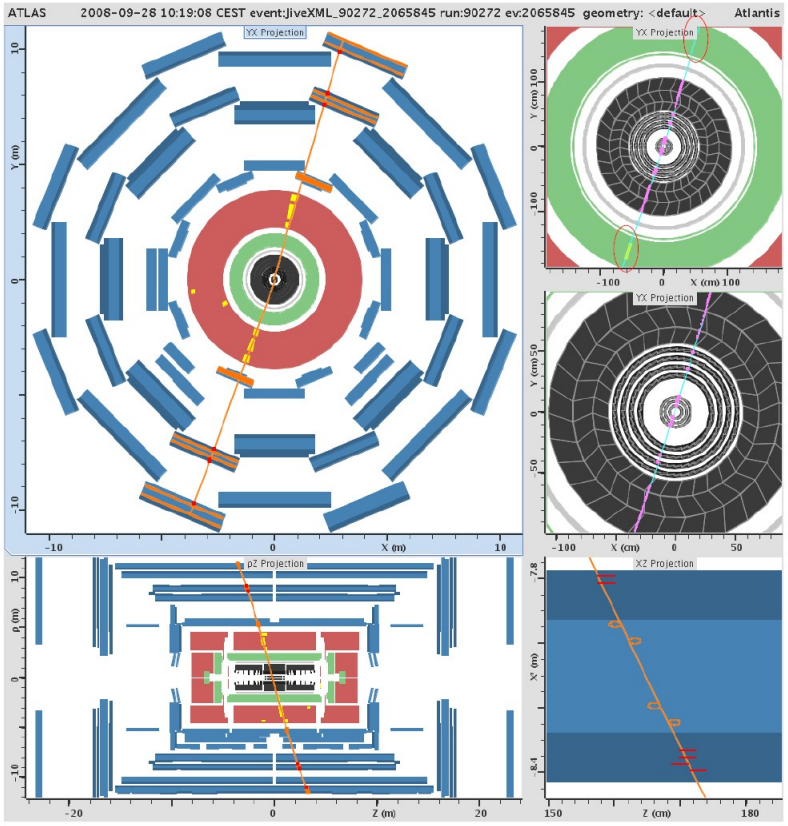
In Situ Commissioning ongoing since 3 years

1994 1999 2004 2009

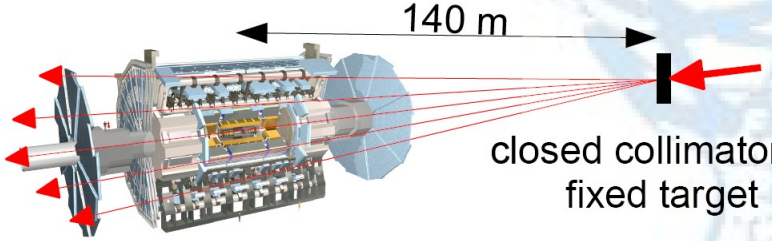


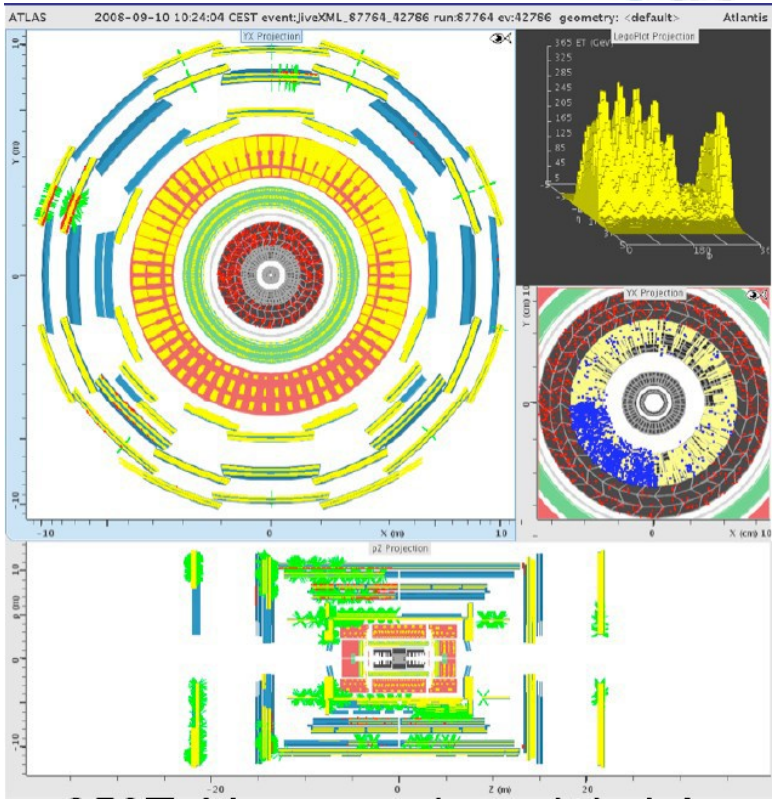
Cosmic muons

Recorded in the LAr calorimeter since 2006



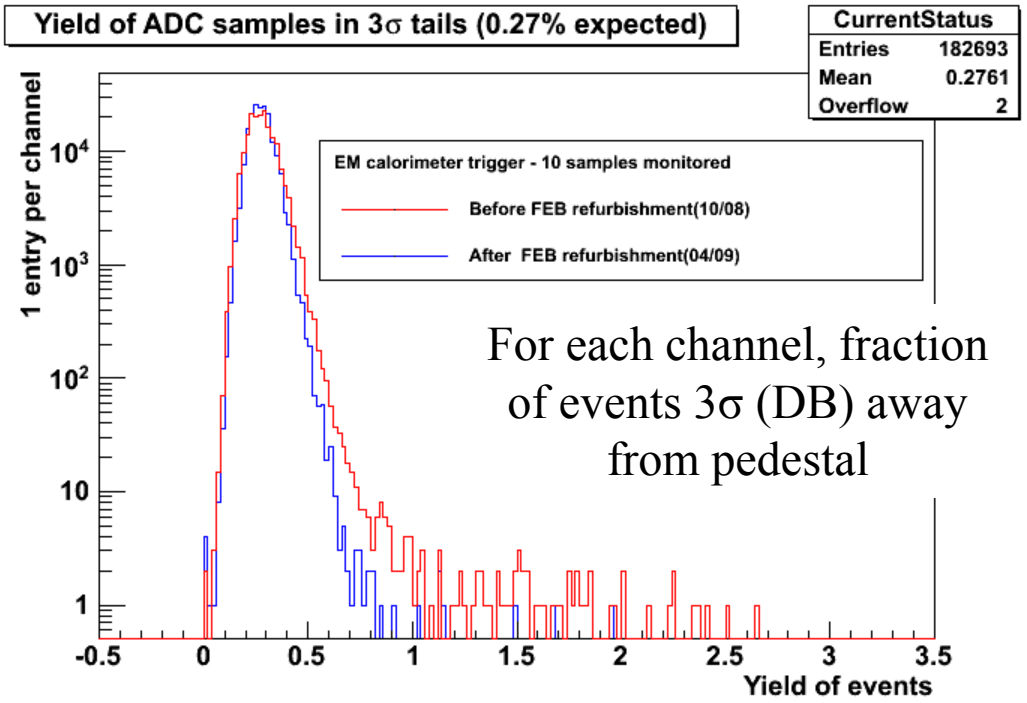
LHC Single beams (Sept. 2008)



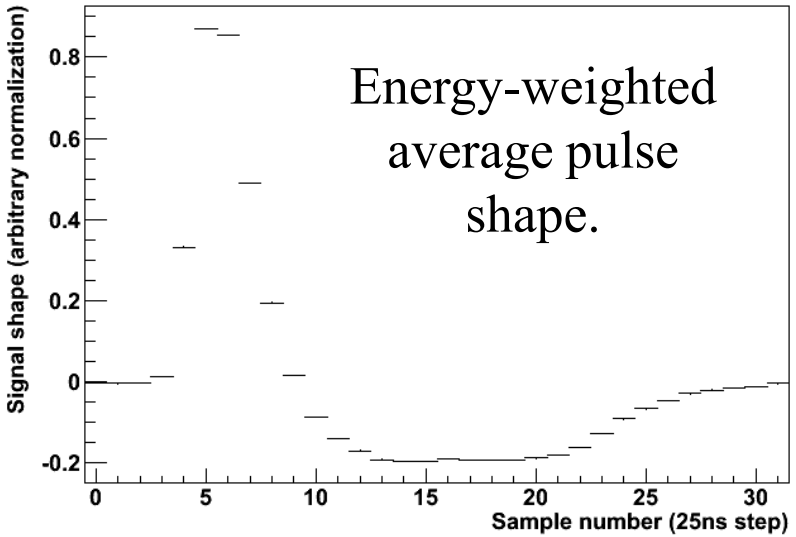


LAr (Online) Monitoring and Data Quality

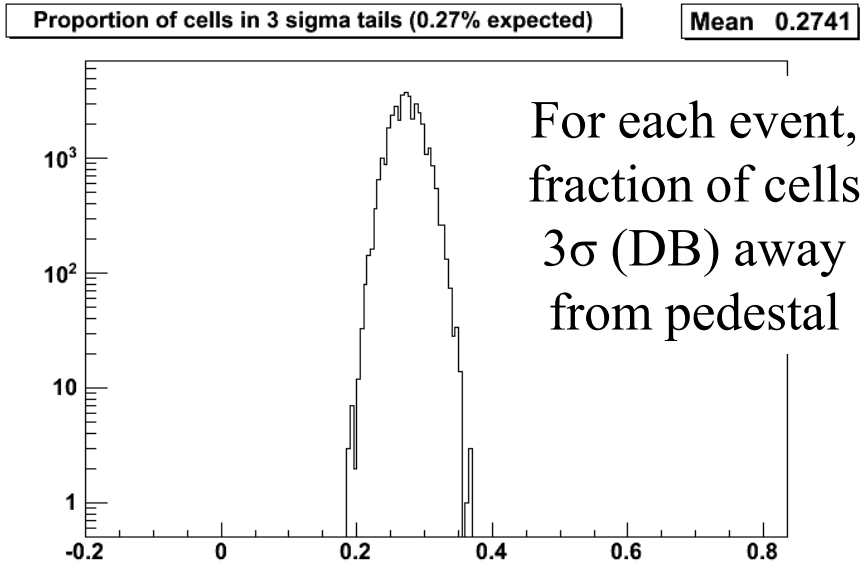
- Extensive suite of monitoring plots and data quality checks for online and offline use
- Energy-weighted pulse shape gives quick check of timing, by trigger and subdetector, and evidence of signal
- Sporadically noisy cells from damaged amplifiers repaired with front end board refurbishment



For each channel, fraction of events 3σ (DB) away from pedestal



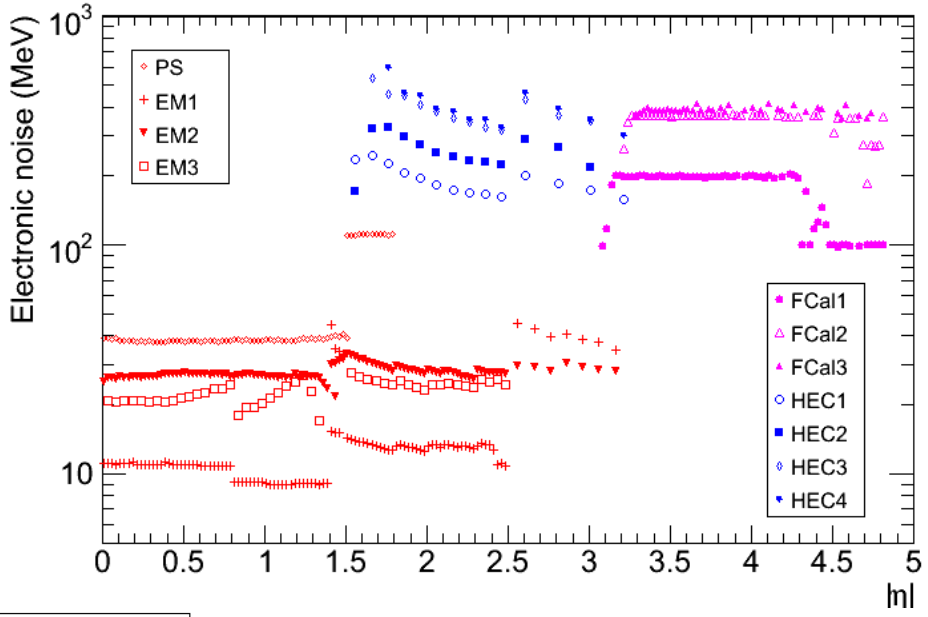
Energy-weighted average pulse shape.

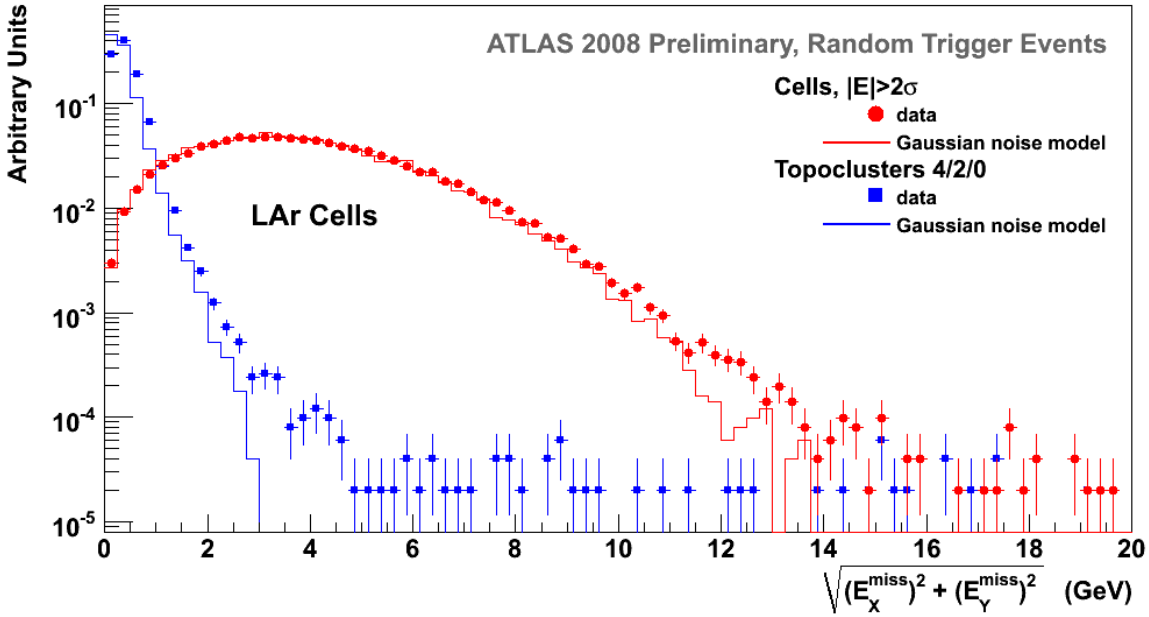


For each event, fraction of cells 3σ (DB) away from pedestal

Noise and E_T^{Miss}

- Electronic noise is measured in pedestal runs, but also in physics runs (random triggers) using the full reconstruction of the cell energy and recorded in the calibration database
  - Varies with layer, η, and subdetector across almost two orders of magnitude





- E_T^{Miss} reconstructed with cells, and with calorimeter clusters with additional noise suppression
- One faulty HV cable contributes significant coherent noise (now replaced)
- Aside from this, distribution is reasonably consistent with incoherent Gaussian noise

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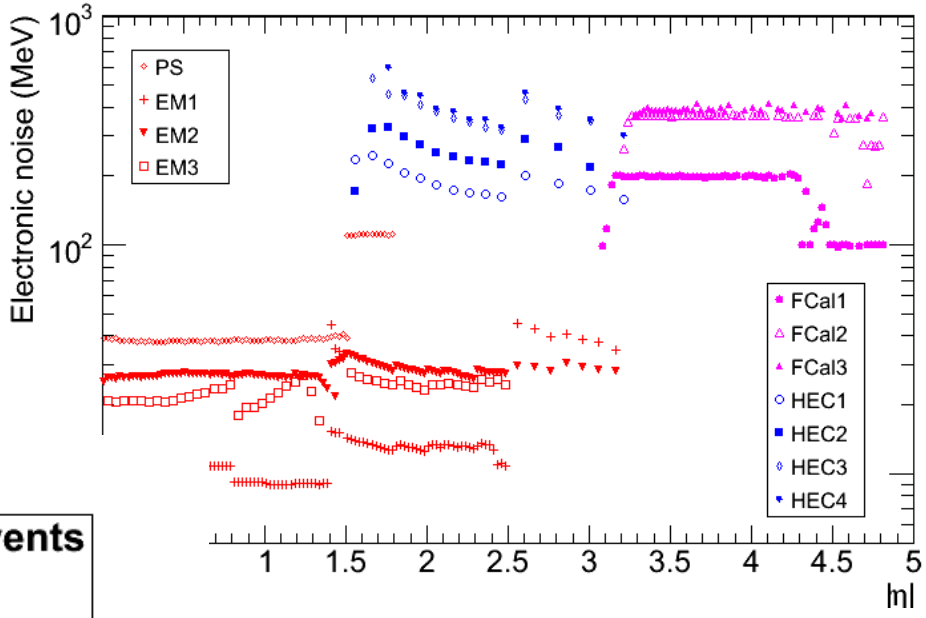

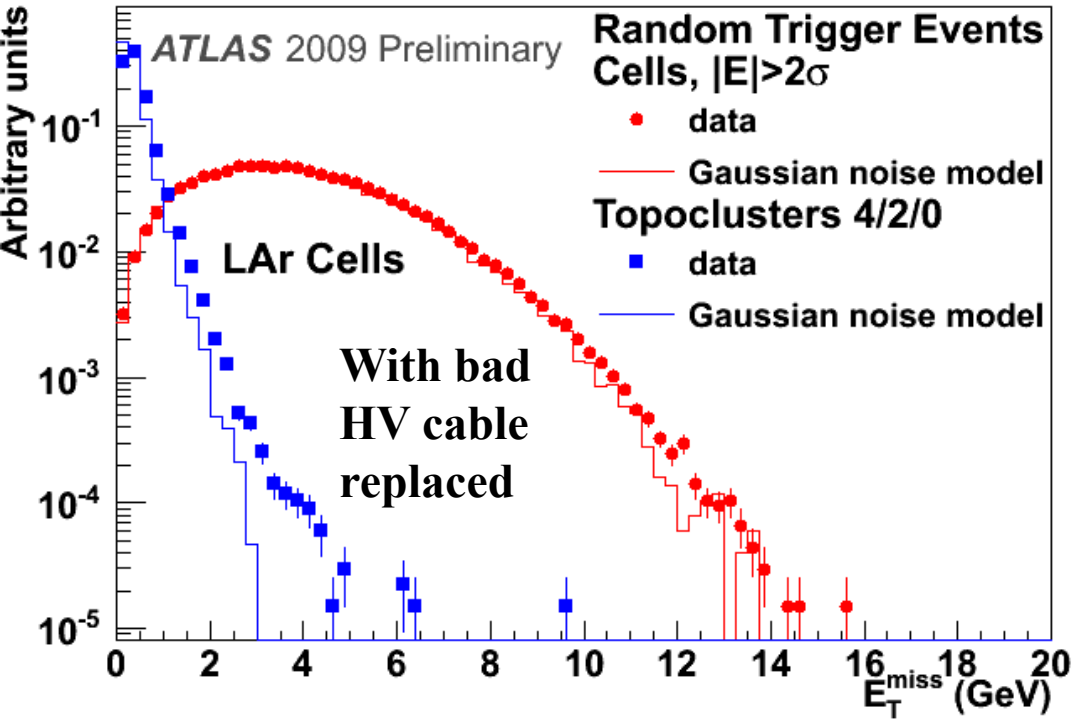

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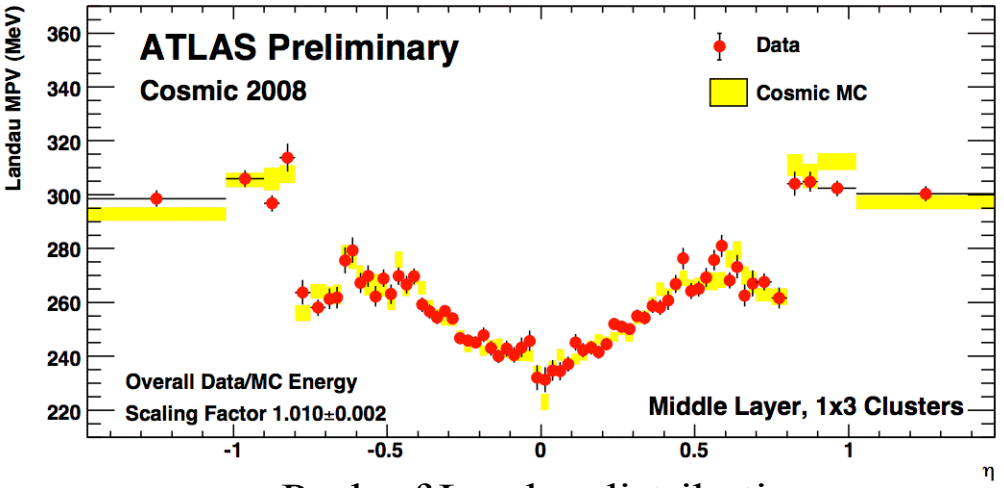
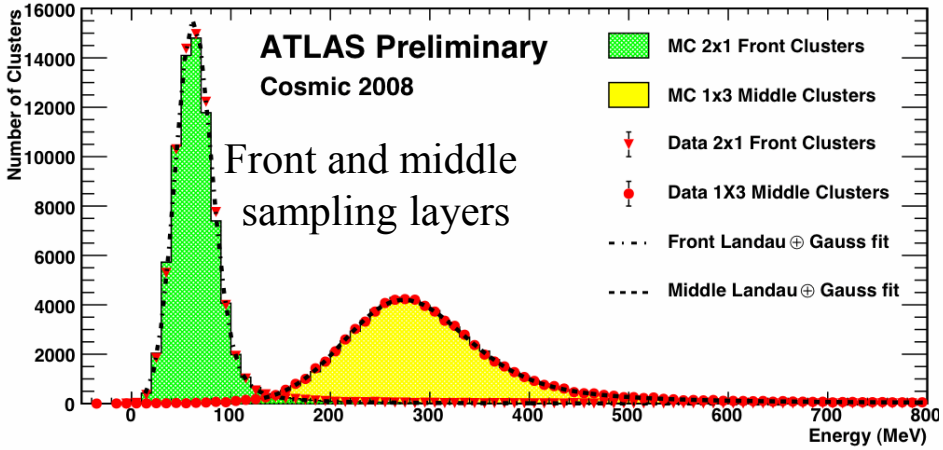
Cosmics as MIP's to Test Response Uniformity

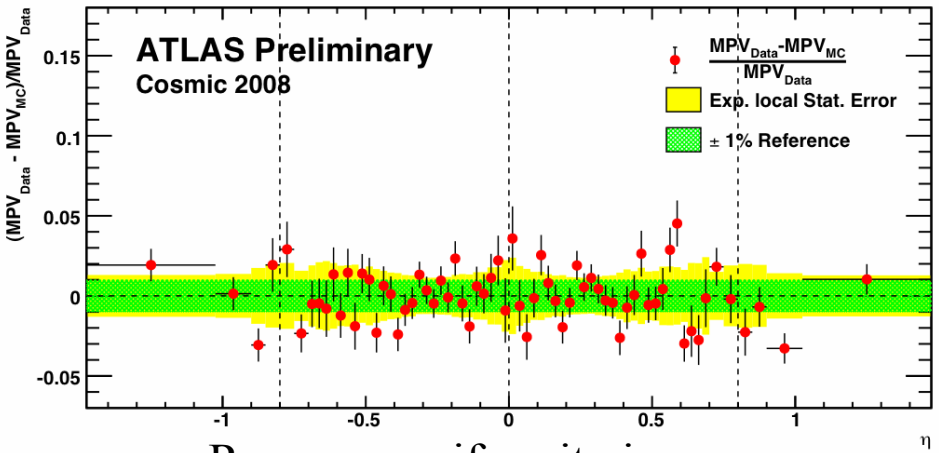
- Cosmic μ's approximate minimum ionizing particles (MIP's)
- Projective muons, passing through center of ATLAS, leave a clear signal in LAr
- Tests calorimeter simulation and calibration
  - Probes non-uniformity of calorimeter response at 1% level



Peak of Landau distribution vs. η



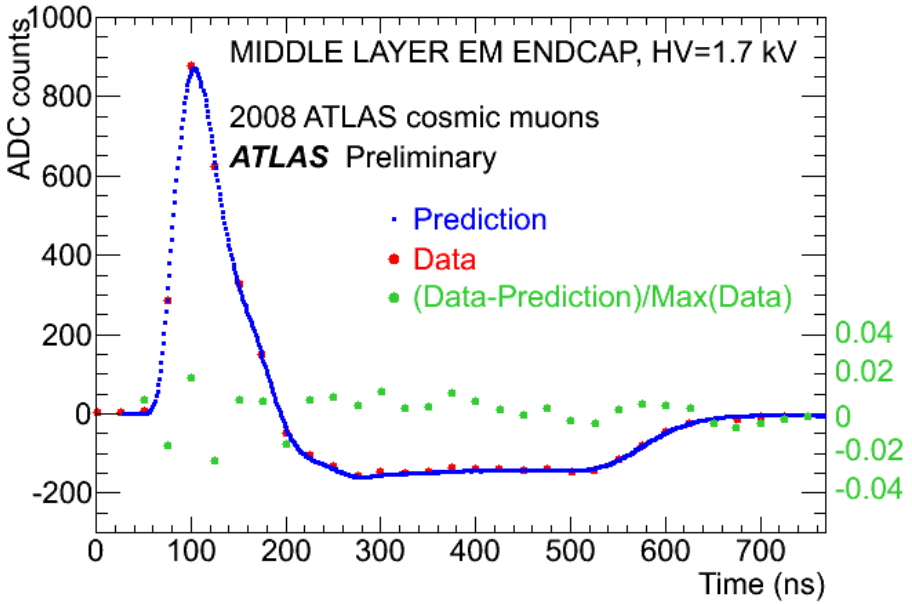
Energy in cluster described by Landau + Gaussian



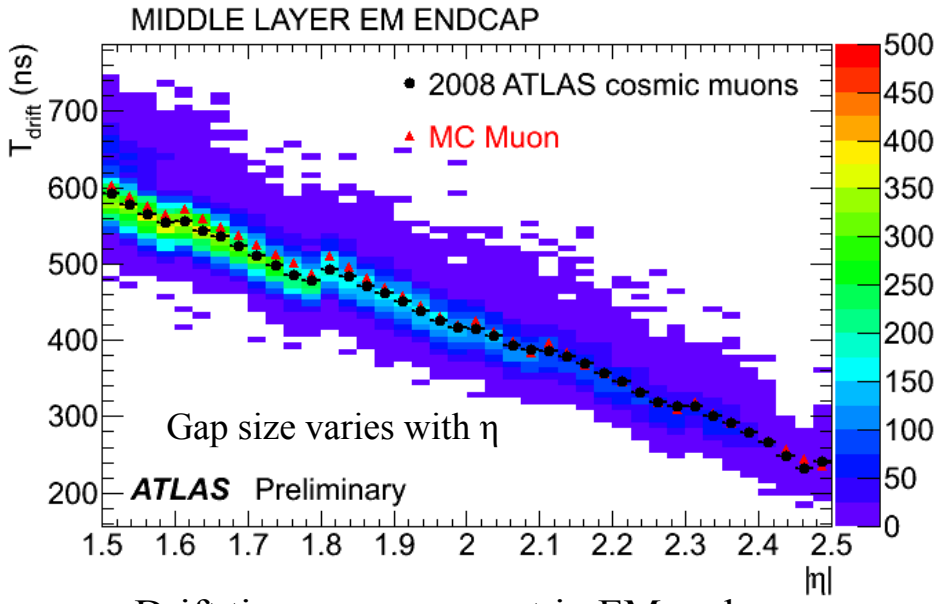
Response uniformity in η

Testing Our Pulse Prediction With Cosmics: Measuring the Drift Time

- Some cosmic runs taken with 32 sample LAr readout (instead of nominal 5)
  - Large event size limits ATLAS trigger rate
  - But, allows detailed studies of signal shape
- Drift time of the freed electrons relates directly to the pulse undershoot
  - Allows *in situ* measurement of drift time
  - Tests ionization pulse model and detector simulation
  - In barrel, allows us to estimate gap uniformity (0.3%) and overall calo uniformity (0.4%)



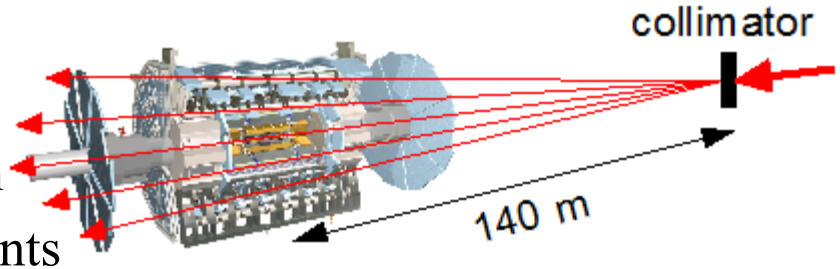
Example pulse shape from cosmic run

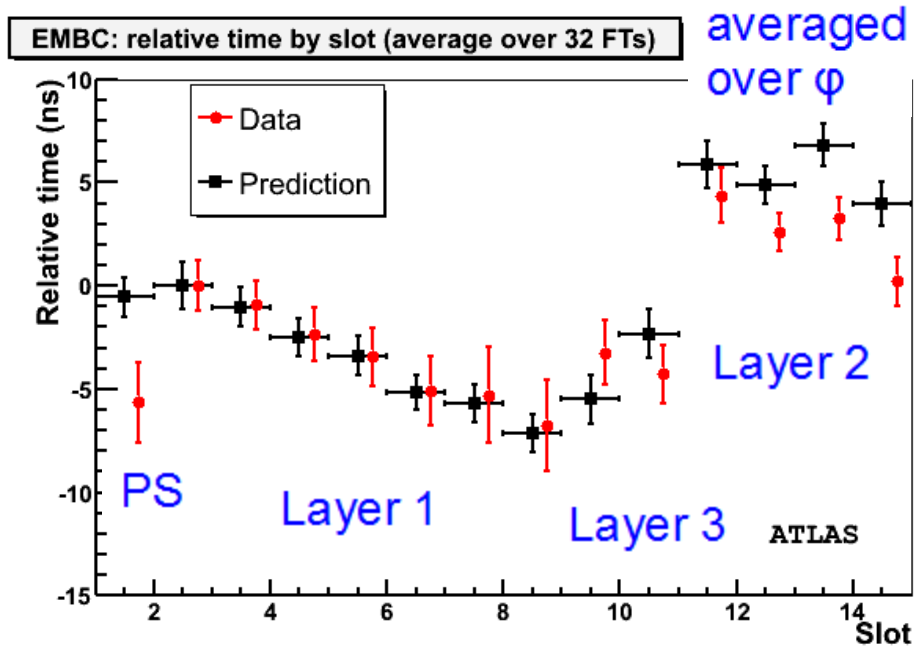


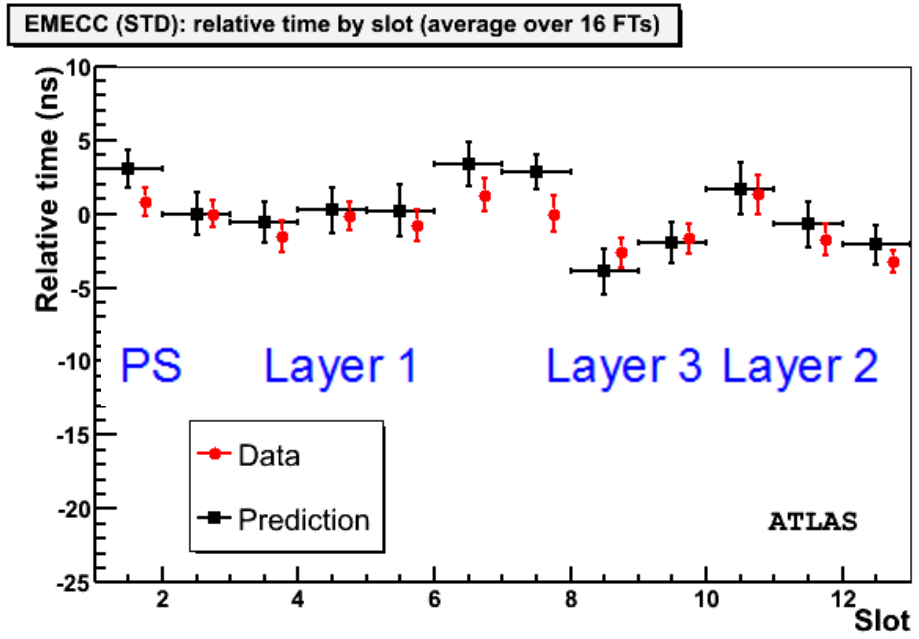
Drift time measurement in EM endcap

Test of Cell Timing With Single Beam Events

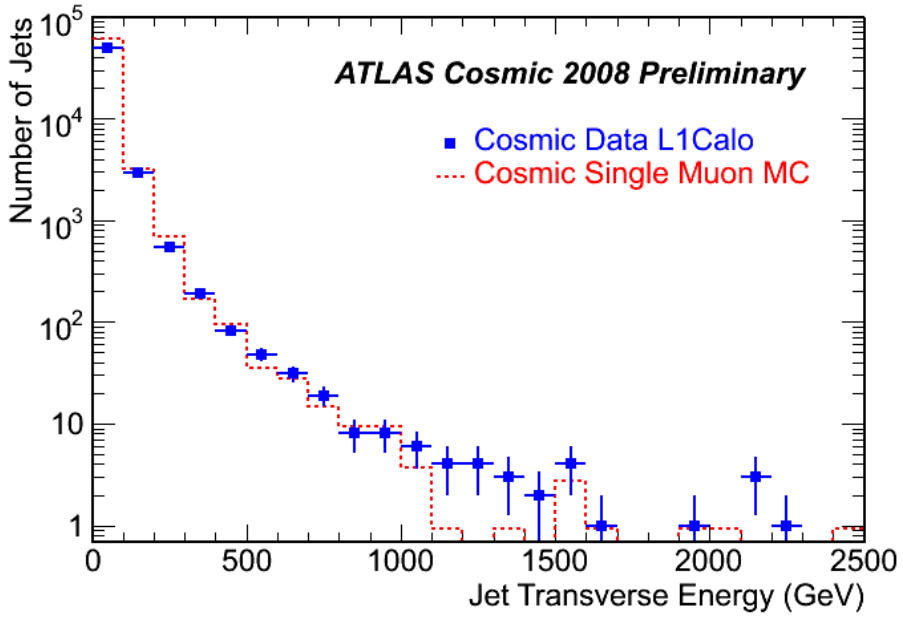
- Single beam and collimator "splash" events
  - Large energy deposit in (nearly) every cell
  - Allows another pulse prediction quality check
  - Also, shown here, we check the time calibration
- Time computed with optimal filtering coefficients
  - Corrected for assumed time of flight
  - Prediction from calibration runs, and known calibration vs. signal path differences
- Agrees at ~2 ns level, except for presampler (and this artifact is now understood)





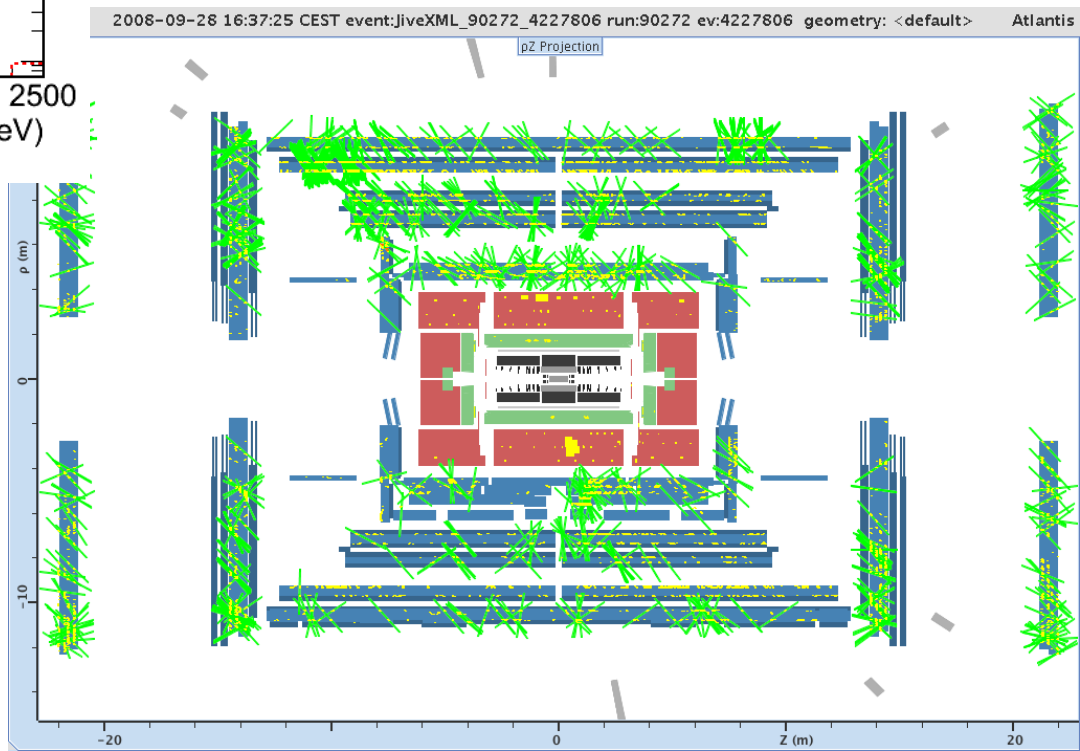


“Jets” in Cosmic Ray Events



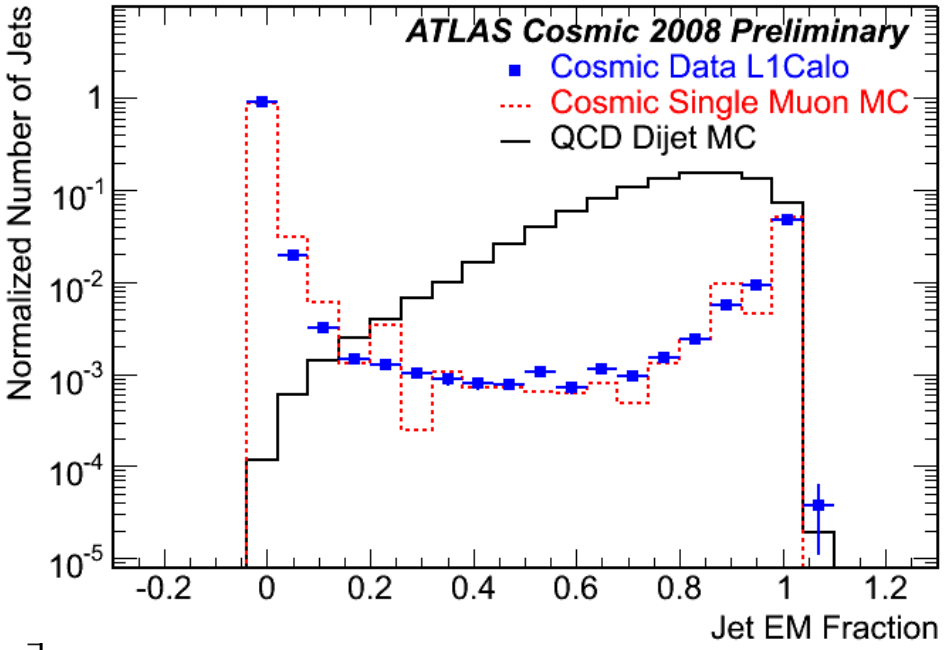
- With cosmics we can commission reconstruction software that will be used for collisions
- And look for unusual phenomena, like TeV jets

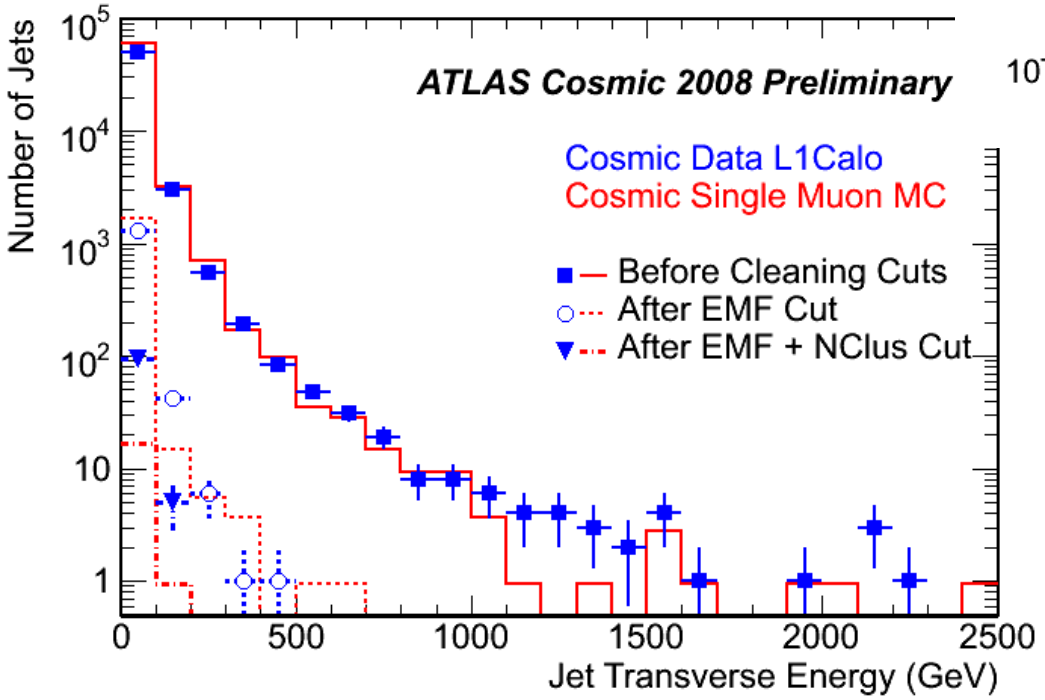
- Cosmic rays can deposit significant energy in the EM and hadronic calorimeters
  - Either via hard *bremsstrahlung* events, or spectacular air showers
  - Good agreement with MC, aside from a few events in the tail (perhaps from air showers, unmodeled in the cosmic MC)



Rejecting "Jets" from Cosmic Ray Events

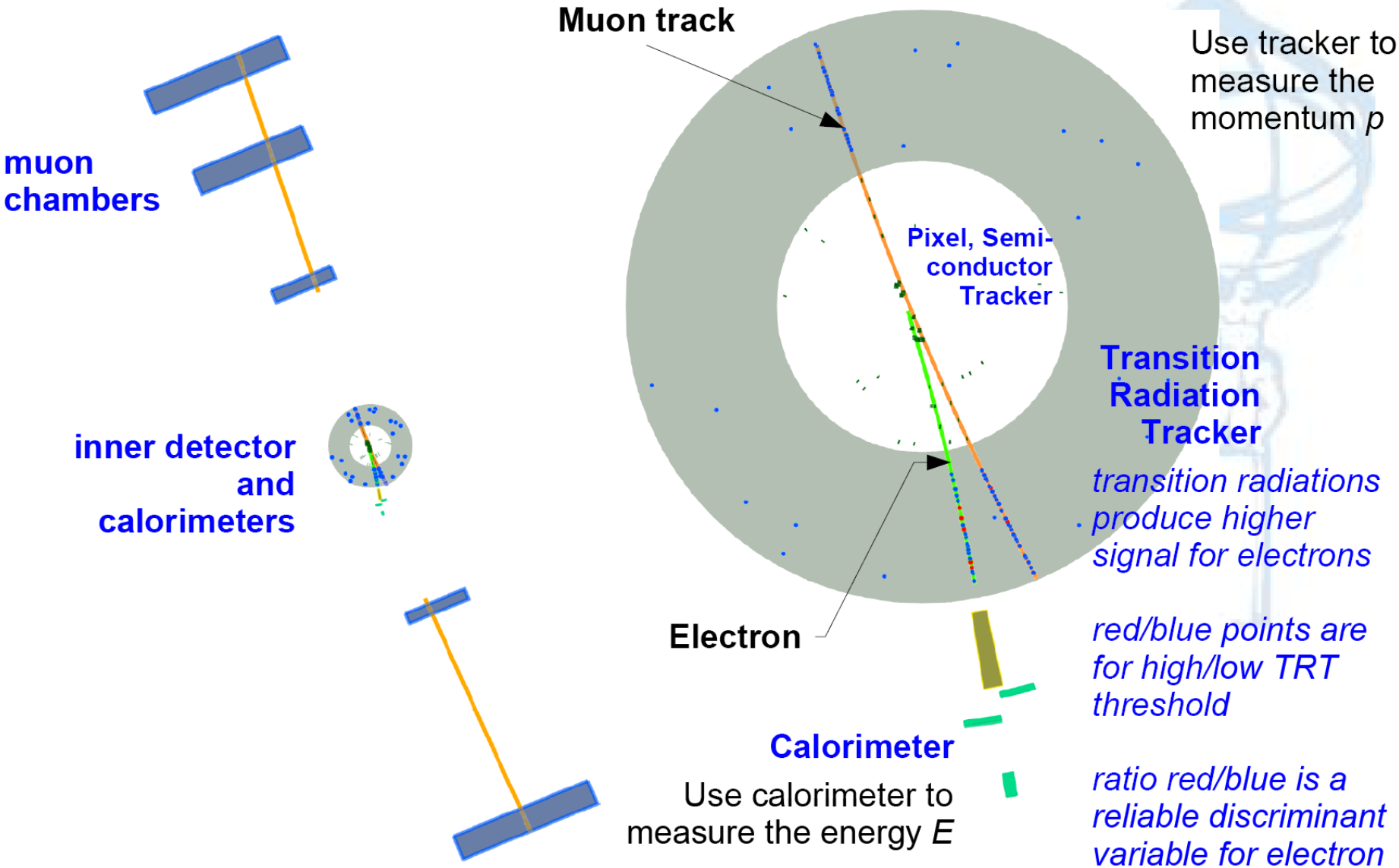
- These "jets" will be a significant background for some physics measurements (e.g. searches for beyond the Standard Model production of monojets + E_T^{Miss})
- Jets from collisions deposit energy throughout the calorimeter





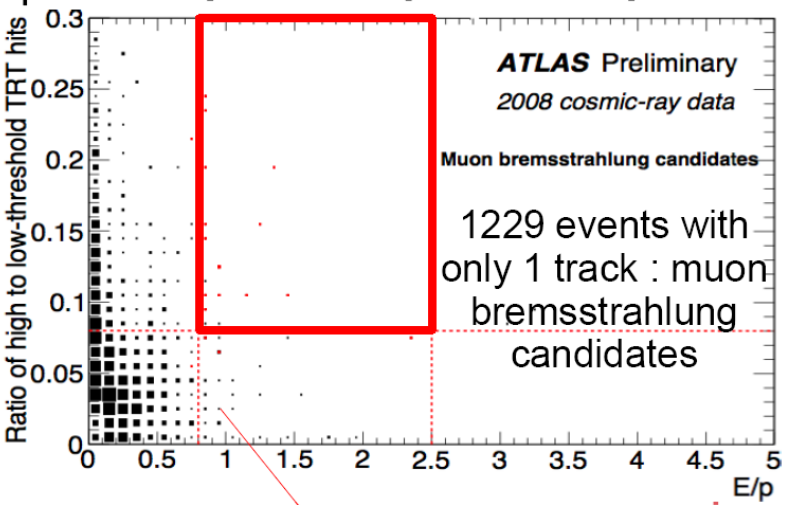
- "Jets" in cosmic ray events are often single hard *brem* interactions in *either* the EM or hadronic calorimeter
- Simple cleaning cuts can almost completely eliminate the background

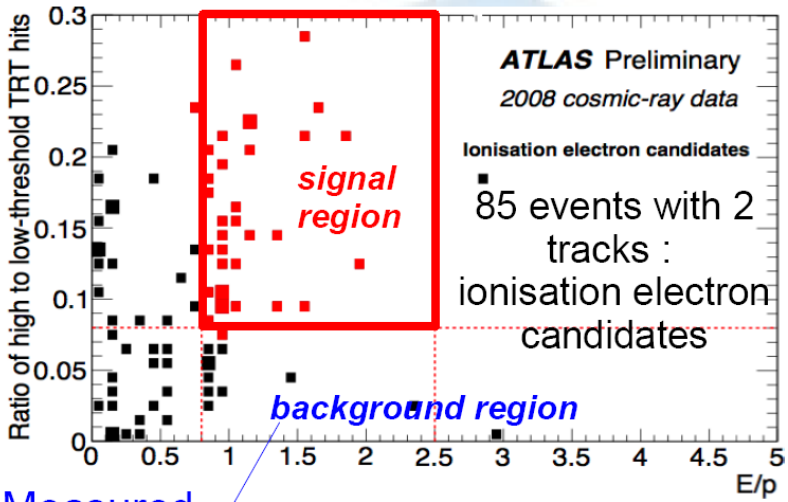
Electrons from Ionisation in Cosmic Muons [1/2]



Electrons from Ionisation in Cosmic Muons [2/2]

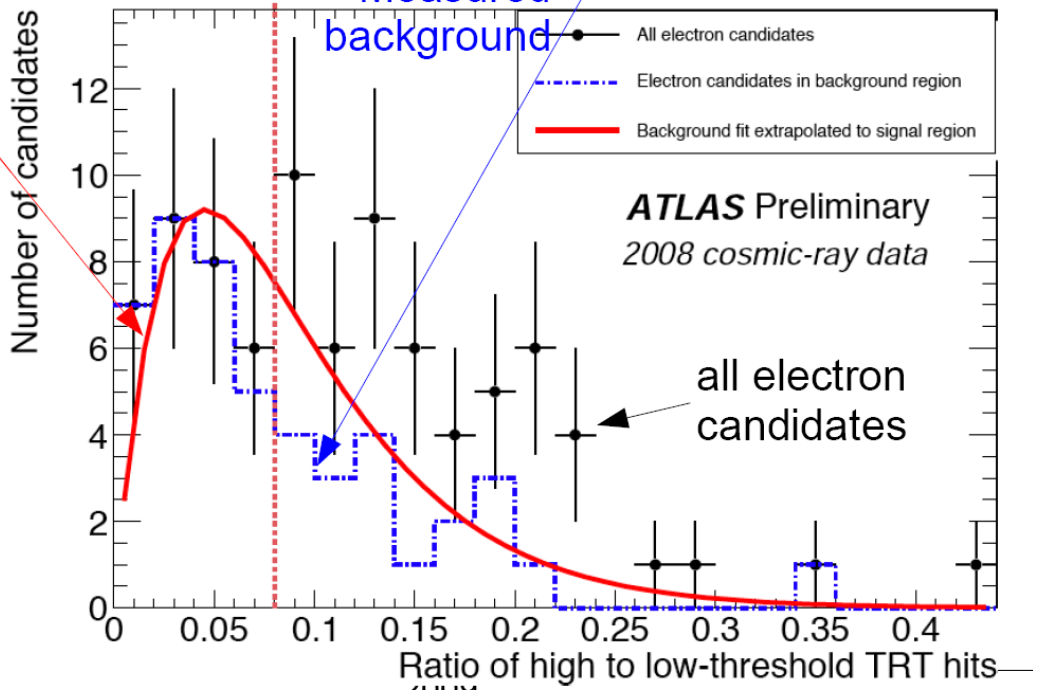
- **EM cluster (E_T > 3 GeV) + loose (downward) track match + electron like shower shape**
  - 1314 events





Expected background shape from muon bremsstrahlung candidates

Measured background



First observation of electrons in the ATLAS detector

Conclusions and Outlook

- The ATLAS Liquid Argon calorimeter is completely installed
  - Extensively commissioned with calibration, cosmic, and LHC single beam runs
  - Data Acquisition, reconstruction, monitoring and data quality infrastructure well developed
- Calibration system, including ionization pulse model, well understood
  - Regularly exercised, with stable calibration constants
- Cosmic ray events extensively studied
  - Gain confidence in reconstruction, calibration, detector simulation
  - Test detector uniformity and drift time, understand bad channels and noise, possible backgrounds to physics
- Ready and waiting for LHC collisions!
  - ATLAS Global cosmic run starts next Monday with 24-7 operation and shift crews
  - LHC beam anticipated in mid-November
  - LHC collisions would be an excellent Christmas present!